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INFLUENCE OF PROFILE ON THE POLLUTION PERFORMANCE OF CERAMIC LONGROD INSULATORS

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Annotation – The long rod insulators with different profiles were shown. In the past the leakage distance was gradually increased because of increased pollution severity. Due to environmental improvement last years in Europe, the new insulator types with a short leakage distance can be applied now.

Key words – outdoor insulators, pollution flashover, insulator profile

INTRODUCTION

The porcelain longrod insulators have been used for over 60 years. The longrod composite insulators with silicone rubber sheath are getting more and more popular last 15 years. The profile of insulators essentially influences their pollution performance. The forming possibilities of long porcelain barrels are rather limited therefore, the shape of porcelain longrods is generally simpler than that of cap and pin insulators. The tradition and limitation in molding technology have caused that the shape of polymer insulators is similar to the shape of porcelain longrods.

During the first 40 years of porcelain longrods the number of sheds joined to the same axial length of about 105 cm increased gradually from 9 at the end of 1930s to 27 in 1970s. The process was the join effect of increasing technology in porcelain forming and increased contamination intensity. During last 20 years in Europe the industrial dust emission was many times reduced. As a result the insulators with short specific leakage distance can be apply not only in rural areas but even close to industrial centers. This paper presents the results of experiments with insulators without sheds and a very short leakage distance carried out at Glogow test station allocated in a cupper smelting plant.

DEVELOPMENT OF LONGROD INSULATORS

Vollkernisolator manufactured in Hermsdorf, Germany in 1919 was the first rod insulator. It had one shed with the diameter of 300 mm and the rod with the diameter of 75 mm. The insulator was applied in Goesgen electric power plant in Switzerland by Motor Columbus company from Baden [1]. The cap and pin insulators that times were not reliable because of cement growth at the pin. The introduction of two flanges and the rejection of pin decreased the number of mechanical failures. The new insulator was called in German the Vollkerninsulator and in English the Motor insulator. The Vollkern insulator was then prolonged and more sheds were added, thus one insulator could withstand higher and higher voltages. The insulators VK 60/2 (fig. 1a) with two sheds or insulators with more sheds (fig. 1b) were connected also into strings and applied for high voltages [2] (figure 1d). The Danish company NORDEN manufactured in 1964 the Aeroform insulators with flat sheds for desert conditions (fig. 1c). Comparing with cap and pin string insulators the longrod insulators have less flanges and smaller weigth.

The first tests of longrod insulators with different profiles under artificial rain were carried out in Germany in 1930. Koppelmann studied so early the influence of diameter, distance and slope of sheds. The formula for the flashover voltage of insulators under artificial rain was proposed on the basis of these measurements:

$$U_{Wet} = 3{,}9\sum S + 1{,}1\sum W \qquad (1)$$

where:
U_{Wet} – flashover voltage (kV),
S - the discharge length in air which bridges the protected insulator parts (cm),
W -the length of creepage distance which is wetted by rain (cm)

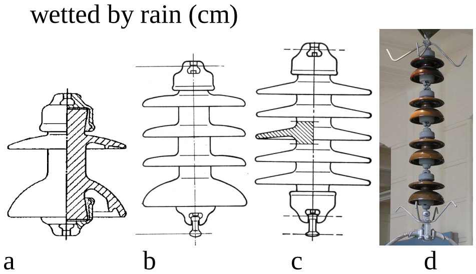


Fig.1. The rod insulators, a – Vollkernisolator VK60/2, b - Insulator N(1+3) [2], c – Aeroform insulator [3], d – string of four Motor insulators.

The flashover voltage under artificial rain of 110 kV insulator with 9 sheds is very high and amounts about 350 kV. However, under heavy pollution the electrical strength of this insulator was found to small. To increase the pollution flashover voltage at the same axial length the creepage distance have to be increased by adding more sheds. The influence of insulator profile on its behavior under pollution were studied first by W. Estorff and W. Weber [4]. Eight prototypes for 110 kV prepared by them are shown in figure 2. One of the most interesting is the insulator with alternating sheds (number 2). This solution resulted from the observation made during the rain tests. The considerable distance between large sheds shall avoid the water cascading. It is worth to note that the insulators with alternating sheds (so called easy grease) were applied much later in 1970s after the positive trials carried out in Great Britain [5]. The insulators with great shed inclination of about 45° have been manufactured in German Democratic Republic after 1954 [6, 7]. The sheds with ribs are similar to the sheds of old cap and pin insulators. The prototypes were tested according to the German standard VDE Leitsaetze fuer die Nebel- und Verschmutzungspruefung von Freiluft-Hochspannungs-isolatoren. The insulators were contaminated by blowing the dust from the brown coal power station to the chamber. Then the insulators were cooled down, placed again in the chamber and wetted by the fog having the conductivity lower than 500 μS/cm. The voltage was increased up to flashover, this measurement was repeated 30 times. The insulator was contaminated again and the flashover voltage was measured. Twelve contamination and voltage cycles were carried out. After 12 cycles, comparing to dry conditions, the flashover voltage of cap and pin insulators K3 decreased to 21% and that of longrod insulators with the number 3 and number 8 decreased to 50% and to 40%. The flashover voltage of insulator with 9 sheds decreased four times to 25% (figure 3). The flashover voltages of remaining insulators lay in the hatched area in the figure 3.

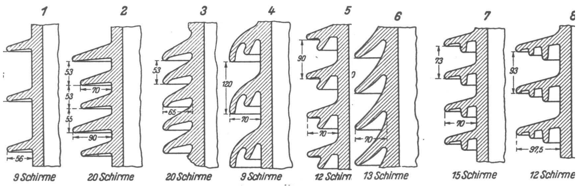


Fig.2. Prototypes of 110 kV longrod insulators manufactured in 1938 [4].

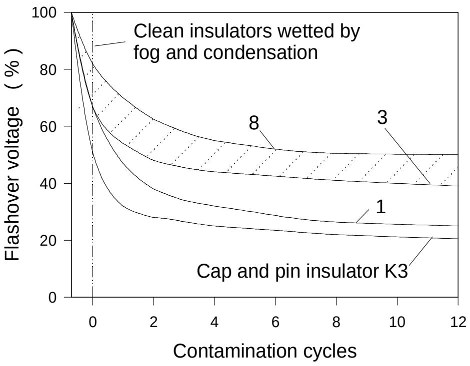
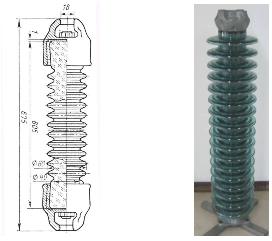


Fig.3. The decrease of flashover voltage as a function of contamination cycles. 100% - the flashover voltage of dry insulators, 1 – the insulator number 1 from the figure 2, 3 – the insulator number 3 from the figure 2, 8 - insulator number 8 from the figure 2 [4]

The longrod insulators are mainly produced of porcelain. The glass rod insulators IFSSS applied in 3,3 kV DC railway traction and glass longrod insulators RSS for 110 kV line were manufactured in Soviet Union. The RSS insulators had the shank diameter of 40 mm and the shed diameter of 60 mm (figure 4a). Two RSS insulators mounted as double string were tested in a rural clean area [8]. The multicone glass post insulators are used in France and Russia [9]. However, these insulators are made of toughened glass shells bind with aluminous cement (figure 4b).



a b

Fig.4. Glass insulators, a – longrod [8], b – multicone post

The insulators with spiral shaped sheds are used in some countries [10], the most popular are Spirelec manufactured in Czech Republic since 1968 (figure 5). The spiral sheds of Spirelec insulator are not inclined. Water flows down along one or two gutters which were formed on the spiral surface. The insulator with stepped sheds is a very interesting solution patented in 1964 (fig. 6). In spite of good pollution performance, the production was limited to about 150 pieces [11].

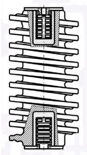


Fig.5. Spirelec insulator.

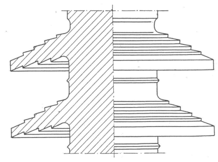
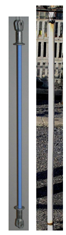


Fig.6. Insulator with stepped sheds

INSULATORS WITHOUT SHEDS OR WITH SMALL NUMBER OF SHEDS

It was shown in the previous section that development of longrod insulators relied mainly on prelongation of creepage distance. As a result, the 110 kV insulators with alternating sheds, 27 sheds and the leakage distance/axial height ratio of four have been produced. Past research and technology efforts were focused on the problems caused by heavy pollution. However, the industrial dust emission decreases in Europe since over 20 years therefore the outdoor insulators are over-dimensioned now. The author investigates the performance of insulators without sheds and insulators with small number of sheds under natural field conditions at the Glogow test station.



a b

Fig.7. Insulators without sheds, a – composite rod insulator, b – porcelain rod insulator [12]

The composite insulator without sheds, the rod diameter of 3 cm and the leakage distance of 105 cm withstand the operating voltage of 75 kV for over four years [12]. The porcelain cylinders with the diameter of 3 cm and leakage distance of 105 cm were installed over one year ago. Up to now no flashover was noted.

MATHEMATICAL MODEL OF POLLUTION FLASHOVER

Obenaus model of pollution flashover assumes the single arc burning on flat narrow surface. For such simple conditions the critical field E_C for which the flashover occurs can be given as following formula:

$$E_C = \frac{U_C}{L} = A^{\frac{1}{n+1}} \cdot r_p^{\frac{n}{n+1}} \qquad (1)$$

where:
X – arc length, A, n – arc constants, L – leakage distance,
r_P – resistance of pollution layer per unit length.

The vertical insulator is a 3-dimension structure with the parameter r_P is a function of height (z coordinate). The unit resistivity r_P can be calculated from the resistance of pollution layer and form factor of insulator f. Thus, the critical field can be written as:

$$E_C = A^{\frac{1}{n+1}} \cdot \kappa_S^{\frac{n+1}{n}} \cdot f'^{\frac{n}{n+1}} \qquad (2)$$

where:
f' – form factor per unit length of leakage distance

The insulator profile in the equation (2) is taken into account in a very simple manner. It is assumed, that the pollution layer is uniform and that only one arc is burning on the insulator. Usually there are a few arcs, therefore the current concentration at the arc foot should be taken into account. Additionally, the arc can burn not only close to the insulator surface but also at a distance bridging a part of leakage distance. These phenomena were worked out in Germany [13] and in Great Britain [14]. The arc is burning close to the surface on cylindrical and on insulators with small number of sheds. In this case the leakage distance utilization factor is close to one. On insulators with small distance between sheds the leakage distance utilization factor is smaller than one (fig. 8).

First research on the influence of insulator diameter on pollution performance was carried out in Germany [16]. The unit resistance r_P in equation (1) decreases as the insulator diameter increases therefore, the flashover voltage falls down. The relationship between the flashover voltage and the diameter of thin cylindrical insulators is very simple. Only one arc burns on the circumference of a cylinder if its circumference is shorter than 2/3 of its height. In this case the flashover voltage describes the following equation [12]:

$$U_F = 1{,}6 \cdot L \cdot D^{-0{,}25} \cdot \kappa_S^{-0{,}25} \qquad (3)$$

where:
U_F – the flashover voltage (kV)
L – the height of cylinder (cm)
D – diameter (cm)
κ_S - surface conductivity (µS)

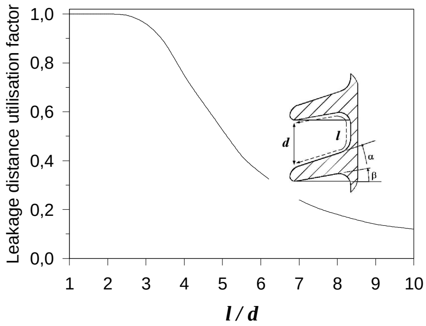


Fig.8. The leakage distance utilization factor as a function of l / d ratio [15].

The flashover voltage of insulators mounted in a small distance is lower than the flashover voltage of single insulator [15]. The examples for such arrangements are double or triple insulator string or a switchgear with double post insulators. The discharges can spring over from one insulator to the neighbouring insulator as a result of different dry band position. I a sense such arrangement can be treated as one insulator with a greater diameter. The flashover voltage on double string of 220 kV cap and pin insulators with a distance of 5 cm can fall down of 25% comparing with a single string [17]. On the contrary the flashover voltage of a V string or a dead end string is higher than that of a vertical one.

SELECTION AND DIMENSIONING OF INSULATORS FOR POLLUTED CONDITIONS

During selection of insulators for polluted conditions the previous discussed factors should be taken into account. The specific creepage distance λ_L can be calculated from the following equation that contains the correction factors.

$$\lambda_L = \lambda \, k_L \, k_D \, k_K \qquad (4)$$

where:
λ - the specific creepage factor of standard insulator that depends on polluted conditions. For very light pollution class $\lambda \geq 1{,}3$ cm/kV and for very heavy pollution class $\lambda \geq 3{,}5$ cm/kV of the r.m.s. phase to phase value of the highest value of the equipment.
k_L – correction factor depending on insulator profile effective creepage distance)
k_D – correction factor taking into account the influence of insulator diameter
k_K – correction factor taking into account influence of configuration of insulation elements

The Russian guide for selection of insulators RD 34,51.101-90 specify the factors k_L, k_D and k_K. The standard draft IEC 60815 {18, 19] gives three ranges for parameters of insulator profile. In the recommended range no worsening of insulator properties should occur and in the permissible range a small reduction of insulator performance is possible. According to IEC draft the shed inclination angle should be smaller than 25°. This recommendation is based on the investigations carried out in the arid regions of Central Asia and at the coast of Caspian Sea [20]. For a coast situated far from the desert, this recommendation seems to be problematic. It is well known that insulators with a great shed inclination perform better than insulators with less inclined sheds [21]. The IEC draft introduces two correction factors. For insulators with the diameter greater than 30 cm the factor K_{ad} and for areas with the altitude higher than 1500 above the sea level the factor K_a should be found according to the paper [22].

The insulators with a very short specific creepage distance of 1,3 cm/kV can be used in very clean areas. These rules are in force in the USA since many years and were accepted in the draft IEC 60815 by introduce the new pollution class "very light". The rod insulators shown in the figure 7 have the specific creepage distance of 0,8 cm/kV. So very high electrical strength is caused by small diameter and excellent self washing properties of rod without sheds. The long rod insulators were tested in 1960s and 1970s under heavy sea and industrial pollution in Great Britain [4], Germany [23Verma] and Poland [24]. These investigations proved the superiority of long creepage distance. This time, in the postindustrial era the insulator profile should be optimized for light and very light contamination conditions.

CONCLUSIONS

The long rod insulators were designed in this time when in Europe a very heavy industrial pollution occurred. Therefore, the development of long rod insulators had relied on increasing of creepage distance at the same axial length.

The reduction in industrial dust emission occurs in Europe for last 20-30 years. Therefore, the insulator profile should be optimized for light and very light contamination.

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